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THE EFFECTS OF INTENSITY OF ILLUMINATION ON PRESBYOPIA, ACCOMMODATION AND CONVERGENCE*

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In the concluding paragraphs of an essay on the effects of intensity of illumination on the near point of vision and a comparison of the results obtained for presbyopic and non-presbyopic eyes, Ferree and Rand[1] of the Johns Hopkins University Research Laboratory of Physiological Optics wrote: "Our purpose is to make an earnest plea that still greater attention be given to the study and care of the presbyopic eye. If, for no other reason, presbyopia is important because it is the common heritage of the race. The mitigation, so far as possible, of the blasting effects of age is our most important scientific problem." Since presbyopia is the common heritage of all men and women who come to the prime of life, it is certainly important that various investigations be conducted concerning the possibility of the substitution of sufficient intensity of light for early presbyopic corrections on the basis that the effects (cited in subsequent paragraphs) produced by adequate light may compensate for an apparent insufficiency of accommodation. In general, it is known that accommodation seems to fail more rapidly than would be expected when once the aid of corrective lenses is accepted and continuously used in presbyopia. In certain cases, therefore, there is the possibility of a choice or of a compromise relationship between the avoidance of strain, on the one hand, and a continuation of the exercise of the power to accommodate and its tendency to preserve that power, on the other hand. At any rate, intensity of light as well as corrective lenses should be borne in mind as one of the aids in presbyopia. Ferree and Rand[1] wrote: "If it is desired to resort as little as possible to corrective aid, the proper conditions of lighting will be found to be of great service. Extremes in either direction should be avoided and careful judgment is needed to preserve the powers of the aging eye, particularly in the early stages of presbyopia. What the effect of accommodation on the properties of the lens is, it is perhaps difficult to say, but innervation and muscle action are accommodative functions and it may be that sometimes they are allowed to

*Submitted for publication June 18, 1936.

atrophy unnecessarily. On the other hand, we are fully cognizant of the fact that no good comes from straining the powers of an organ, particularly at a stage of life when strain is the most dangerous."

Beneficial Effects of Increased Illumination

Among the beneficial effects of increase of intensity of light on the efficiency of performance and of the general welfare of the eye may be mentioned:

1. There is an increase in the visibility of objects. It has been demonstrated by experimental work that: (a) there is an increase of acuity or an increase in the power to discriminate detail, (b) there is a greater speed in discrimination and a still greater increase in the power to sustain clear discrimination of details, and (c) there is an increase in speed of discrimination involving a change in adjustment of the eyes for different distances.

2. Other conditions being equal, there is an optimal intensity of light under which ocular discomfort and other signs of strain and fatigue are decreased.

3. There is an increase in the range of distance over which a given detail, with a given relationship to the background, can be discriminated. In other words, the near point is closer to the eyes and, correspondingly, the far point recedes. As Ferree and Rand stated: "This effect on the near point is particularly important in the case of young eyes having a small range of accommodation and in the eyes of the aged."

4. There is an increase in the tolerance of a defective coordination of accommodation and convergence and an increase in the apparent power to separate these two functions. Low tolerance in this particular may be a very important factor in the eye strain experienced in low degrees of uncorrected hyperopia, myopia and early presbyopia. Lighting conditions, it may be remarked in passing, may be responsible for or act as contributing agents in innervational dysfunctions or imbalances of the extrinsic ocular muscles as well as in the development of tropias. One may easily verify the effect produced by intensity of light on the phoria and duction tests, especially when made with the fixation target at the ordinary reading distance, by varying the illumination on the test chart from a few foot candles to, let us say, 20 foot candles. Some marked differences in data will be obtained in many instances under ranges of illumination of 3 to 20 foot candles. These researches are in their infancy, however, but it is to be hoped that various investigators will engage in some practical routine or office tests on this matter. In other portions of this article reference will be made to the work of Luckiesh and Moss concerning the fatigue of convergence, induced by reading, as a function of intensity of illumination.

5. There is an increase in tolerance of any refractive error. The correction of small defects is not as imperative so far as subjective experience is concerned; small inaccuracies in correction are more negligible.

Ferree and Rand[2] concluded that, in every refractive anomaly that comes under advisement, two important avenues of treatment are open: the correction of the refractive system to form as clear an image as possible, and the correction of lighting conditions to give the retina the optimal power to discriminate detail. "At best the refractionist can go only so far in the task set to him. It remains for the lighting specialist to minimize the harm of the residual defects. Colorless light, a glareless field correctly balanced as to distribution and brightness, good diffusion to give a minimum of glare on the work and adequate intensity will go a long way in improving the vision and health of any eye. The care and treatment of the defective and sick eye is an important specialty in lighting. In the case of such eyes it should be remembered that the effects of bad lighting are almost unbelievably extreme to those who have not had either experience or the chance to observe the effects on others."

6. There is an increase in the sharpness of retinal image formed by the refracting system due to the contraction of the pupil. The narrowing of the pupil excludes the effects of aberration and other irregularities resulting from the periphery of the lens and cornea, and reduces the size of the diffusion circles by narrowing the cone of light from each point of the object.

Effects of Changes of Illumination on Near Points

The presentation which has just been given concerning the various factors which contribute to the increased efficiency of performance of visual tasks and which are induced by increase of intensity of illumination would lead one to expect that changes in intensity of illumination, through a range of 1 foot candle to 25 foot candles, would produce definite effects on the near point measurements in both presbyopes and non-presbyopes. The results of the researches of Ferree and Rand show that there is a considerable effect of increase of intensity of light on the distance of the near point and, therefore, on the apparent diopters of accommodation at all ages. There is a much greater effect for presbyopic than for non-presbyopic eyes, and for middle-aged and old than for young eyes.

Obviously, it is to be expected that a considerable range or spread of results would be obtained for different individuals as measurements are made on near points under various intensities of illumination. The experimental results indicate these general tendencies:

1. In the group without presbyopia in which the ages of the individuals ranged from twenty to thirty years of age, with an increase from 1 to 25 f. c. (foot candles) the distance of the near point decreased within a range extending from 3-26 mm., or 3 to 22 per cent. For the group of individuals who were thirty to forty years of age, the corresponding figures are 18-45 mm., or 11 to 28 per cent as the range.

2. In the presbyopic group in which the ages of the individuals tested ranged from forty to fifty-three years and in which there were

reading corrections (additions of 1 to 2 diopters), the effect of change of intensity of illumination on the near point was most marked among those requiring the higher reading additions. Among those persons whose correction for near work was less than 1.5 diopters, the distance of the near point decreased 90-160 mm., or showed a change of 18 to 28 per cent for an increase of intensity of light from 1 to 5 foot candles. For an increase from 1 to 25 foot candles the distance decreased 170-250 mm., a range of 32 to 41 per cent. In those cases in which the reading correction was 1.75 diopters and more, an increase of illumination from 1 to 25 foot candles decreased the distance of the near point 180-690 mm., or a range of 43 to 73 per cent.

3. The ranges of increase in apparent diopters of accommodation for these groups are as follows: For those without presbyopia who were less than thirty years of age, there was an increase in apparent diopters of 0.18-0.98, or 2 to 11 per cent for an increase of intensity of 1 to 5 foot candles, and for those who were more than thirty years of age, there was an increase of 0.4 to 1.19 diopters, or 7 to 19 per cent. For a change from 1 to 25 foot candles the increase in apparent diopters was 0.27-2.44, or 3 to 29 per cent for the younger group and 0.72-2.38 diopters, or 11 to 39 per cent for the older group. For the presbyopic group whose correction for near vision was less than 2 diopters, the increase in apparent diopters of accommodation was 0.33-0.86, or 22 to 40 per cent for an increase of intensity from 1 to 5 foot candles, and for an increase of illumination from 1 to 25 foot candles there was an increase in apparent diopters of accommodation of 0.61-1.53, or 48 to 71 per cent.

4. From the tables of data and the curves showing the relationships of changes in intensity of illumination and increase in apparent diopters of accommodation, the significant point brought out is the very great benefit of increase of illumination (even as high as 100 foot candles) experienced by the presbyopic individual.

5. Contraction of the pupil is responsible for a portion of the apparent increase in accommodative amplitude at higher intensities of illumination. From their investigations Ferree and Rand concluded that approximately a third of the percentage change in the near point produced by increasing the illumination from 1 to 25 foot candles is due to the greater focussing action of the smaller sizes of pupil at the higher intensities; approximately two-thirds of the effect is inherent in the sensory and perceptive actions.

In order to emphasize some of the important conclusions which have been drawn regarding the beneficial effects of adequacy of light, I am giving three tables of illustrative data (tables 1, 2 and 3). In a consideration of these data it should be noted that, in general, the intensity of illumination indoors and under ordinary workaday conditions of artificial illumination is not over 5 foot candles. All of the present-day researches on light and vision led to the conclusion that 20 to 25 foot candles on the object of regard is a fair average requirement. Luckiesh

and Moss indicate that intensities of illumination of 100 foot candles are desirable for visual tasks as difficult as reading ordinary black print on white paper. From the data at hand, however, I am of the opinion that 25 foot candles of illumination will produce the major part of the beneficial effects produced by adequate illumination.

Significance of Findings Concerning the Effects of Increase of Illumination

The data recorded in tables 1, 2 and 3 indicate very clearly that the problems of vision and of lighting are intimately associated. They definitely point out: (1) the influence of intensity of illumination on visual acuity and discriminative power; (2) the effect of increase of intensity of illumination on the approach of the near point to the eye and the increase in the apparent diopters of accommodation; (3) the pronounced beneficial effects of sufficient illumination in presbyopia; (4) the possibility of the substitution of the various effects produced by increased illumination for a portion of the accommodation normally requisite at the reading or other close working distance, and (5) the possibility of the use of increased illumination on the close work at hand in certain types of innervational dysfunctions of ocular muscles and in latent or apparent tendencies to squint. This may be particularly true in cases of esophoria or accommodative overconvergence, in which an increase in equivalent accommodative action produced by light may be caused to act as the substitute for the actual accommodation produced by ciliary innervation, thereby eliminating the esophoric condition and tendency to overconvergence.

TABLE 1

The Effect of Increase of Intensity of Illumination on the Near Point of an Emmetrope (Twenty-three Years), Corrected Myope (Forty Years) and Presbyope (Fifty-five Years) (From Ferree and Rand)

	Emmetrope		Myope		Presbyope	
Intensity Illumination (f.c.)	Near Point (cm.)	Apparent Diopters Accommodation	Near Point (cm.)	Apparent Diopters Accommodation	Near Point (cm.)	Apparent Diopters Accommodation
0.5	10.35	9.66	25.8	3.88	61.0	1.64
1.0	9.82	10.18	21.2	4.72	51.0	1.96
2.5	9.72	10.29	19.9	5.03	42.5	2.36
5.0	9.64	10.37	18.8	5.32	39.0	2.56
10.0	9.56	10.46	17.6	5.68	36.0	2.78
15.0	9.45	10.58	17.1	5.85	34.5	2.90
20.0	9.40	10.64	16.8	5.95	32.5	3.08
25.0	9.35	10.70	16.6	6.05	31.0	3.23
37.5	9.30	10.75	16.4	6.10	28.5	3.51
50.0	9.24	10.82	16.3	6.15	27.5	3.64
75.0	9.14	10.94	16.0	6.25	24.5	4.08
100.0	9.04	11.06	15.8	6.33	22.5	4.44
Maximal change	1.31	1.4	10	2.55	38.5	2.8

TABLE 2

The Effect of Intensity of Illumination on the Near Point of Vision in Presbyopia (From Ferree and Rand)

Case	Age of Patient	Reading Correction	Near Point (cm.)			Apparent Diopters Accommodation		
			1 f.c.	5 f.c.	25 f.c.	1 f.c.	5 f.c.	25 f.c.
1	40	+1.D.S.	46	33	27	2.17	3.03	3.70
2	40	+1	50	41	33	2.00	2.44	3.03
3	46	+1	78	62	53	1.28	1.61	1.89
4	50	+1.50	58	45	38	1.72	2.22	2.63
5	50	+1.50	48	37	29	2.08	2.70	3.45
6	50	+1.50	51	41	31	1.96	2.44	3.23
7	51	+1.75	52	37	29	1.92	2.70	3.39
8	51	+1.75	40	29	22	2.50	3.45	4.55
9	52	+1.75	106	52	37	0.94	1.95	2.70
10	52	+1.75	58	46	33	1.74	2.17	3.03
11	53	+2	64	35	17	1.56	2.86	5.88
12	53	+2	56	43	25	1.79	2.33	4.00
13	55	+2	73	43	30	1.37	2.33	3.33
14	55	+2	70	37	22	1.43	2.70	4.55
Average - - - - - - -			60.7	41.5	30.5	1.75	2.49	3.53

TABLE 3

Representative Data Concerning the Effects of Intensity of Illumination on the Near Point and the Apparent Diopters of Accommodation

Criterion	Foot Candles 1	10	50	100
1. Near point in a case of				
a. Emmetropia	9.82 cm.	9.56 cm.	9.24 cm.	9.04 cm.
b. Myopia	21.2 cm.	17.6 cm.	16.3 cm.	15.8 cm.
c. Presbyopia	51.0 cm.	36.0 cm.	27.5 cm.	22.5 cm.
2. Apparent diopters accommodation in case of				
a. Emmetropia	10.18	10.46	10.82	11.06
b. Myopia	4.72	5.68	6.15	6.33
c. Presbyopia	1.96	2.78	3.64	4.44

	Foot Candles 1	5	25
3. Average near point and apparent diopters accommodation in group of non-presbyopes	12.6 cm. 8.3 D.	11.7 cm. 8.9 D.	11.7 cm. 9.4 D.
4. Average near point and apparent diopters accommodation in group of presbyopes	60.8 cm. 1.75 D.	41.5 cm. 2.5 D.	30.5 cm. 3.55 D.

These investigations, as a whole, point to the necessity for increased standardization in ocular refraction. Among these may be mentioned: (1) standard test charts, both for far and near vision, making use of scientific standards rather than letters of the alphabet, (2) standards of illumination of test objects, and (3) methods and means for the determination of the effects of changes in illumination on the ocular func-

tions. Those who are equipped to investigate these problems in connection with the work of routine refraction may be able to contribute additional data and facts of clinical importance.

In concluding this portion of the presentation concerning the effects of intensity of illumination on ocular functions, I am quoting from the publications of Ferree and Rand:[2] "There is much greater need of the higher intensities of light for old than for young eyes. Among the reasons why an old eye needs more light, the following five may be mentioned: its smaller pupil, the inferior imaging power of its refracting media; the diminished transparency of the media; the decay in all its processes of adaptation and adjustment; and the failing powers of the retina itself.

"In the treatment of the presbyopic eye the refractionist is apt to consider only the refractive and accommodative situation. The physician, however, must take all the functions of the eye into account. The errors of refraction and the failure of accommodation are not the only defects in the old eye which can be remedied in the prescriptions given. All the possible refractive corrections that can be given to the presbyopic eye will not clear up the media, or add to the discriminative powers of the sensorium."

There is, apparently, a very simple mode of procedure which lies within the powers and province of the refractionist to prescribe, namely, "the intensity of light which is required to give the eye in question the acuity which in his judgment is feasible and advisable to attain. It would also be of great service to the intelligent patient to know what acuity he is able to obtain at different intensities of light and, therefore, what type of work he may hope to be able to do, and what intensity of light he needs to be able to do this work. All that is required to render this service is that the examination be made at a sufficient number of intensities of light selected with reference to the case in hand, that the results be given to the patient and that recommendations be made within the judgment of the examiner. That is, there is to be included in the prescription given to the patient a correction not only for the image-forming function, but for the other functions which make of the eye an organ of vision."

Effects of Illumination on Convergence Reserves (Adductions)

The results given in some recently published investigations of Luckiesh and Moss[6] indicate that the decrement in the amplitude of convergence of the internal recti muscles due to reading for one hour under an intensity of illumination of 1 foot candle was three times as great as it was under 100 foot candles. These evidences of ocular fatigue practically disappear within ten minutes after cessation of reading. Such data, so the investigators believe, provide additional support to their contention that in the neighborhood of 100 foot candles is desirable for reading under ordinary conditions.

The work of Luckiesh and Moss was concerned primarily with the effects of critical visual effort on the tonus of the extrinsic ocular muscles. While this method of investigating a phase of ocular fatigue—fatigue, in the physiological sense, being regarded as a temporary impairment of function following continued use—is not a new one (*vide*, Howe[3]), the recent investigations are unique in that they involve the performance of a given visual task under conditions which are found in everyday life.

A special form of ophthalmic convergence ergograph was built by Luckiesh and Moss. The ensemble, consisting essentially of rotary prisms operated by a motor and a recording mechanism, was used to cause contraction of the internal recti muscles until diplopia occurred. The technic involved may be designated as a "repeated effort method," since a series of twenty successive responses of convergence to the point of diplopia were recorded on a kymograph immediately preceding and subsequent to a period of reading. In addition, a third set of measurements was made after a ten-minute period of rest during which the demands on the functions of convergence and accommodation were minimized. This cycle of tests was repeated at intervals of three or four days for each of the nine adult subjects. The intensity of illumination under which the reading was done was alternately 1 and 100 foot candles for the successive periods of test.

For purposes of analysis and interpretation it was considered desirable to maintain the same fixational distance, that is, fourteen inches, during the periods of reading and operation of the ergograph. By reason of the experimental data of Ferree and Rand, indicating that the near point of vision is a function of the brightness of the visual field, all ergographic measurements were taken under identical brightness conditions. "Actually, the test object appeared upon an extended white field which was illuminated to an intensity of 10 foot candles. This arrangement thus introduced retinal adaptation as a variable, since the reading was performed under brightness conditions differing from those of the ergograph field."

Results on Convergence Fatigue

The average amplitudes of convergence of the internal recti muscles for various experimental conditions are given in table 4. Decrements in the amplitudes of convergence of 3 and 1 diopters were obtained after reading for one hour under intensities of illumination of 1 and 100 foot candles respectively. From their data Luckiesh and Moss believed they were warranted in the assumption that muscular fatigue produced by reading, as indicated by tonicity of the internal recti muscles, is approximately three times as severe under the lower level of illumination as it is under the higher level. Furthermore, they stated: "This conclusion is even more significant in view of the fact that the subjects read nearly 10 per cent faster in the latter case (i.e., under 100 foot candles of illumination), though they were cautioned to read at a natural rate."

TABLE 4

*Convergence Reserves (Adductions) in Prism Diopters Before and After Reading Under the Specified Intensities of Illumination (From Luckiesh and Moss)**

	Illumination			
	100 Foot Candles		1 Foot Candle	
Subject	Before Reading	After Reading	Before Reading	After Reading
1	12.3	12.0	13.6	10.0
2	19.6	18.2	20.9	15.4
3	18.3	15.4	18.1	14.8
4	25.1	25.4	25.1	24.1
5	6.9	7.4	7.7	6.4
6	19.2	18.4	17.9	16.8
7	19.0	18.0	17.2	13.9
8	10.1	8.0	13.8	9.7
9	16.5	14.6	16.7	13.0
Geometric mean	15.3	14.3	16.0	13.0

*The individual data represent the arithmetic mean of at least five separate tests.

TABLE 5

Data on Convergence Reserves, in Prism Diopters, During Reading and After a Period of Rest (From Luckiesh and Moss)

Intensity of Illumination, 1 Foot Candle

Subject	Before Reading	After Reading	After 10 Minutes Rest
1	17.1	13.9	17.0
2	23.4	18.2	22.9
3	14.6	11.6	13.3
4	....	....	....
5	7.5	6.1	7.4
6	19.6	17.2	19.0
7	16.6	13.4	16.5
8	13.8	9.7	14.2
9	16.8	12.7	16.3
Geometric mean	15.5	12.3	15.2

An analysis of the data (table 5) taken ten minutes after an hour's reading indicates that the decrements in amplitudes of convergence, which were found to be produced under the test, have disappeared. If, therefore, such decrements in convergence power are indicative of ocular (internal recti muscles) fatigue, it would appear that recovery is rapid during a brief period of casual seeing. It would be of considerable interest and of practical importance if a series of investigations were carried out, under low and relatively high intensities of illuminations, concerning the innervational status (phoria), fusional convergence reserves, and accommodative demands and reserves. It is probable that increased illumination would be advantageous in conditions of high accommodative exophoria and low positive fusional reserves and perchance of greater assistance in the maintenance of distinct binocular single vision in cases of low amplitudes of accommodation (for example, presbyopia) and low

convergence reserves. When these conditions of high innervational demands and low functional reserves are found to exist and tests are made before and after an hour of reading under low illumination (1 foot candle) it is likely that greater decrements will be found and that a greater period of rest will be needed before the decrements in convergence amplitude will disappear. These statements are in line with the expressions of opinion of Luckiesh and Moss: "It is conceivable that the time required to dissipate muscular fatigue may eventually prove to be an important datum in the field of ocular hygiene for determining the duration of rest periods. Such data would be particularly significant when applicable to children and to those with severe visual disorders."

Effects of Illumination on Various Ocular and Body Functions

By way of summary, the essential data relative to the effects of increase of illumination on the near point of vision or change in apparent diopters of accommodation, visual acuity, muscular tension[5] while reading and other physiologic effects[7,8] and convergence reserve after reading for an hour, are given in table 6.

TABLE 6

Effects of Change of Intensity of Illumination on Visual and Body Functions

Criterion	Foot Candles 1	10	50	100
1. Visual acuity a basic factor in reading	100%	130%	155%	170%
2. Nervous muscular tension while reading	63 gm.	54 gm.	49 gm.	43 gm.
3. Decrease in heart rate while reading one hour	10%			2%
4. Decrease in convergence reserve after reading one hour	23%			7%
5. Near point in a case of				
a. Emmetropia	9.82 cm.	9.56 cm.	9.24 cm.	9.04 cm.
b. Myopia	21.2 cm.	17.6 cm.	16.3 cm.	15.8 cm.
c. Presbyopia	51.0 cm.	36.0 cm.	27.5 cm.	22.5 cm.
6. Apparent diopters accommodation in case of				
a. Emmetropia	10.18 D.	10.46 D.	10.82 D.	11.06 D.
b. Myopia	4.72	5.68	6.15	6.33
c. Presbyopia	1.96	2.78	3.64	4.44
7. Nature — shade of a tree (summer day), 1,000 f.c.; gloomy day, 200 f.c.				

Recommended Foot Candles

The results of these recent investigations[4] which we have been discussing indicate very clearly that ease of seeing and an increased efficiency or reduced expenditure of energy on the part of the eyes, as well as other organs of the body, are produced by an increase in the intensity of illumination. The question may well be asked: What is the desirable inten-

sity of illumination? The simplest answer, but an impractical one from the standpoint of artificial lighting, is that the ideal intensity of illumination for exacting visual tasks should be approximately that in the shade of a tree on a summer's day, or about 1,000 foot candles. This statement, moreover, clearly indicates that there is little need to fear that a visual task will be overlighted artificially. There may be, however, improperly placed and incorrect types of illumination. Possibly the best answer to the question of desirable foot candles of intensity on indoor work is the recommendation that they be increased considerably above the low levels of a few foot candles which have been universal in homes, factories and places of business and in which there has been no appreciation of or consideration given to the various factors that affect visibility and comfort in seeing.

Considering the various economic and practical aspects of the subject, the consensus of opinion among illuminating engineers, as well as physiologists and psychologists who are interested in visual problems, may be expressed in the following recommendation: 100 foot candles or more for quite severe and prolonged tasks such as fine needlework, fine engraving, fine assembly, sewing on dark goods and discrimination of fine details of low contrast; 50 to 100 foot candles for severe and prolonged tasks such as proof reading, drafting, difficult reading, fine machine work, and average sewing; 20 to 50 foot candles for moderately critical and prolonged tasks, such as clerical work, ordinary reading, common bench work, and average sewing and other needle work on light colored goods; 10 to 20 foot candles for moderate and prolonged tasks of office and factory and, when not prolonged, ordinary reading and sewing on light colored goods; 5 to 10 foot candles for work which involves good seeing ability, but more or less interrupted or casual, and which does not involve discrimination of fine details or low contrasts; 2 to 5 foot candles may be said to be the danger zone for ordinary visual tasks and for quick and certain seeing. Such low illuminations may be sufficient and satisfactory for viewing objects without regard to details and for casual seeing.

Measuring Light

It is quite an easy matter to obtain the desired intensities of light. If a 60-watt incandescent lamp is used, a photometer or meter for measuring foot candles will register about 75 foot candles at a distance of one foot and, at two feet, about 20 foot candles. If the bulb is a 100-watt lamp, more than 150 foot candles are obtained at a distance of one foot and about 90 to 100 foot candles at a convenient distance for ordinary close work. Or, again, if a 40-watt bulb is used, there will be an intensity of illumination of 10 to 12 foot candles on a surface two feet away from the lamp and about 5 foot candles if the distance is three feet. The general law underlying the intensity of illumination falling on a screen held at various distances from the same lamp states that the intensity of illumination varies inversely as the square of the distance from the light source.

Photometric measurements by methods commonly used in the past in physical and engineering laboratories are not practical tests to be carried out in homes, offices and factories. The advent of the photo-electric cell, however, provided an electric eye which, under specified conditions, delivered an electric current which could be read on an instrument, commonly spoken of as an "ammeter," and which was directly proportional to the intensity of illumination. In recent years another distinct advance has been made through the development of photovoltaic cells. Such a photovoltaic cell, of which one type is referred to in the literature as the "photronic cell," consists essentially of a thin metallic disk on which there is a film of light sensitive substance; the metallic disk serves as the positive terminal and a metal collector ring in contact with the light-sensitive surface forms the negative terminal. Since the current developed is directly proportional to the illumination and since such photovoltaic cells are relatively inexpensive and may be used in direct combination with a simple and inexpensive type of ammeter, the ability to determine intensities of illumination in any situation or position and with ease, quickness and accuracy is made possible. The development of this simple light meter has placed in the hands of those interested in vision and in lighting a practical means of determining the lighting conditions under which visual tasks are performed.

A Visibility Meter

An instrument, known as the "visibility meter," was developed recently by Luckiesh and Moss[9] for purposes of appraising the visibility of various objects or visual tasks and for specifying foot candles of light for adequate illumination on a rational basis. This meter, now available at a nominal cost to those interested in the problems of vision and lighting, consists essentially of two colorless or neutral filters, with precise gradients of transmission factor, which may be rotated simultaneously in front of the eyes while looking at an object, or while performing a visual task. The observer holds the instrument in approximately the same position as eyeglasses are worn and slowly turns a disk which rotates the gradients until the visual threshold or borderline of performance of the visual task is reached. Measurements of relative visibility may be made in a few minutes.

The instrument also carries a scale of recommended foot candles, in which the values used as an "arbitrary compromise between the foot candles necessary for barely seeing and the enormously higher foot candle levels for easiest seeing" as indicated by recent investigations. Many of the details concerning the instrument and methods of using it are given in the publications of Luckiesh and Moss and may be obtained by addressing them at the Research Laboratories, General Electric Company, Nela Park, Cleveland, Ohio.

General Considerations Regarding Inadequate Lighting and Ocular Deficiencies as Causes of Useless Expenditure of Energy

Most adults use their eyes from twelve to fifteen hours a day for seeing near or distant objects. The burdens which are imposed on the eyes during the hours spent every day in looking at objects, often very small and detailed, which are held at arm's length or less are considerable, for the eyes must accommodate and converge properly in order that distinct binocular single vision may be obtained. Judging from the data obtained in several industrial investigations, the eyes are engaged in exacting tasks about 70 per cent of the working hours. Even under adequate lighting, with normal vision and adequate reserves of accommodation and convergence, it has been estimated that there is a consumption of a quarter of the bodily energy in the processes of distinct binocular single vision. The ease of seeing, when vision is normal and the powers of accommodation and convergence are adequate, is controlled almost entirely by sufficient and proper lighting. When the lighting is inadequate and improper and when poor vision and ocular insufficiencies are present, the consumption of bodily energy is increased, for various reasons, above the normally necessary amount. For vision which is poor, either because of the need of proper optical assistance or on account of insufficient light, causes uncertainty, tension, annoyance and distraction. These unfavorable reactions and results, produced by increased expenditures of energy, contribute to ocular discomfort and to other trains of symptoms exhibited by abused eyes.

We know that fatigue caused by visual tasks is but a part of the bodily fatigue which comes on as a result of the various kinds of activities in which the body engages under the suspension and guidance of light. Fatigue, in the physiologic sense, may be considered to be a temporary impairment of function following continued use. Eye fatigue is not a simple product of inadequate or improper lighting, for it may involve inflammation of ocular membranes, fatigue of ocular muscles or undue innervational demands and the effects of annoyance in concentrating the attention or trying to see. Hence, all the factors which tend to increase the ease of seeing should decrease the likelihood of needless expenditure of energy from visual causes.

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A NEW CONCEPTION OF THE NATURE OF THE VISUAL THRESHOLD*

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Introduction

Recent advances in nerve physiology have necessitated modifications of some of our conceptions regarding the nature of the visual process. These modifications have resulted primarily from considerations regarding the rôle of the synapse in nerve conduction. Nerve impulses, initiated by end-organ activity in the eye, do not follow an uninterrupted course in their ascent to the cerebral cortex, but rather traverse a pathway which involves a chain of several neurones. An explanation for the existence of such a situation necessarily involves the question of the function of the synaptic connections between these neurones. Creed[7], in 1931, considered this problem and emphasized the inadequacy of the "relay station" concept as an explanation for the synaptic connection. These connections are not to be regarded as relay stations for the transmission of nerve impulses from neurone to neurone, but rather as centers where convergence of nerve pathways affords possibilities for interaction between various trains of impulses. This interaction may consist in the combination or summation of excitatory processes of different origin, or in their mutual control and modification. Evidence for such interaction effects at these points of convergence has been clearly demonstrated in the investigations of Sherrington and his collaborators upon the reflex activity of the spinal cord (Creed, Denny-Brown, Eccles, Liddell, and Sherington[8]), and there is ample reason to assume that the concepts derived from these studies of reflex action are applicable, as working hypotheses, to considerations dealing with the mechanism of vision. (For a more complete and general account of the evidence relating to the problem of nervous processes in vision, see Graham.[11])

The Problem

Among the many recognized problems in human vision, the general problem of "spatial effects" has become of increasing amportance for visual theory. Stated simply, the known facts regarding spatial effects

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are (*a*) that a variation in the size of the retinal area stimulated has an effect similar to that produced by a corresponding variation in light intensity, and (*b*) that the effect obtained by stimulation of one area of the retina is, to some extent, dependent upon the nature of the stimulation of adjacent areas. These observations have served as points of departure for a great many experimental attacks. Many of the early investigators (Abney[1]; Piper[19]; Abney and Watson[2]; and others) concerned themselves primarily with empirical quantitative formulations of the various effects demonstrable at the threshold. That no generalized formulation could be obtained was shown later by Kleitman and Piéron[17] who pointed out that, because of the "heterogeneity of the retina," it is unlikely that the "area effect" can be described in terms of a simple law. Furthermore, the various quantitative formulations that have been advanced have been of such varied form that they have complicated the issue rather than given an understanding of the mechanism responsible for the effects.

It was not until the work of Adrian and Matthews[3, 4], in 1928, that a concrete explanation of spatial effects was made possible. These investigators, in recording impulses from the optic nerve of the Congor eel, found that spatial effects are of great importance in determining the nature of the nerve discharge. The latent period of the optic nerve discharge was found to decrease when (*a*) the retinal image is increased in area, and when (*b*) the number of separately illuminated areas is increased. As Adrian and Matthews point out, the shortening of the latent period with increased area must be considered as due to an interaction process. Since the application of strychnine had the effect of facilitating the interaction over an increased range, it was concluded that this interaction is of a summative type and must be localized in the synaptic layers of the retina.

More recently, Granit[14] has shown that the typical area effects are demonstrated in the behavior of the retinal potential of the decerebrate cat, i.e., by a decreased latent period with increased area.

Finally, an observation by Graham[10] is in harmony with the interpretations made by Adrian and Matthews as to the synaptic locus of the spatial effects. This investigator demonstrated that, in the eye of the horseshoe crab *(Limulus polyphemus)* which lacks internuncial neurones, there is no interaction between adjacent areas. This is evidenced by the fact that the latent period for response of the fiber attached to the fastest acting sense cell does not decrease as the number of sense cells brought into activity is increased.

Because of the structural similarity of the eel retina and that of the human, one might well expect to find similar explanations for the effects obtained in human vision. This expectation is realized in the work of Granit and his co-workers (Granit[13]; Granit and Harper[16]; Granit and Hammond[15]; Graham and Granit[12]) who have succeeded during the last few years in demonstrating the importance of spatial effects in the

human retina at high intensities of illumination. These researches have involved the use of flicker as an indication of retinal excitation; and the results may be interpreted as showing functions of the human retina which parallel those of the excised preparation. Granit's "four spot" experiment shows that the critical flicker frequency of four spots is higher than the critical frequency of any one spot alone; further, it was found that this increase in critical frequency rises as the four spots are brought closer together. This effect was found to be greater in the periphery than in the fovea (a result to be expected on the basis of the anatomical differentiation of these areas). In a later experiment, Granit and Harper found that when two retinal areas are stimulated simultaneously the resulting fusion frequency is higher than when either one of the areas is stimulated alone. This rise increases gradually as the areas are brought closer and closer together. The authors interpret this observation as indicating increased lateral summation with increased proximity of interacting components.

The results of Geldard[9] are in harmony with the above-mentioned observations. Geldard found that the threshold for foveal stimulation decreases with an increase in the intensity of peripheral stimulation.

The experiments described above show that, beginning with the experiments of Adrian and Matthews, a great advance has been made in our knowledge of the mechanisms underlying spatial effects in vision. The earlier experiments, referred to above, have been relatively unproductive in contributing to this knowledge. Since, however, the threshold and threshold determinations play such an important rôle in the formulation of visual theory, it would seem that inevitably the threshold type of analysis must be brought into line with the more recent observations. Further, it would seem that, if these effects were demonstrable in human vision within limits by the technique of sensory experimentation, it should be possible to carry on further researches on the synaptic basis of visual reception and ultimately to formulate a description of these processes. Such a program might well be productive of valuable facts and inferences for our knowledge of central visual mechanisms.

During the past year the author[5] has published the results of an investigation which, in line with such an approach, was concerned with a description of a typical synaptic process which seems to play a rôle in the retina similar to that which it plays in the spinal cord. The activity demonstrated is the summation of subliminal excitatory effects. Further analysis of the phenomenon seems to be of significance in that it demonstrates certain facts concerning the nature of the threshold itself.

The method which has been used is the following: The threshold for two areas separated by varying distances is determined, as is the threshold for either area alone. The interpretation in terms of the spatial summation of subliminal stimuli seems warranted by the finding that, within limits of spatial separation, the threshold for the two areas is lower than that for either one alone.

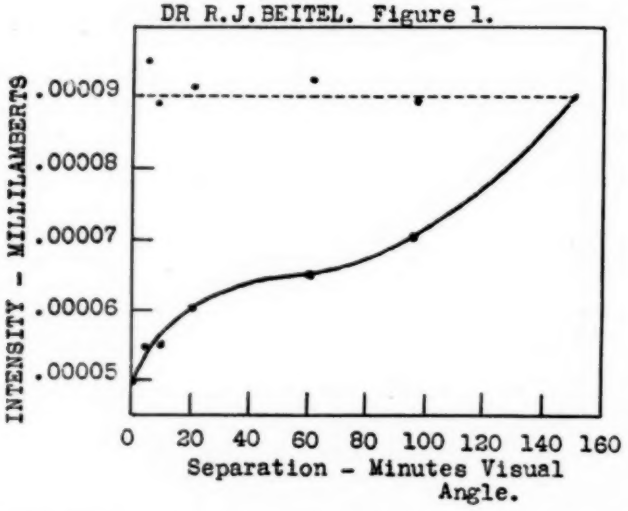
Apparatus and Procedure: Peripheral Determinations

The apparatus and procedure were of the conventional type used for determinations of the threshold. (For a more complete description of the apparatus and procedure, I refer you to my original paper[5].)

The apparatus was set up in a dark room and was constructed so as to allow the presentation of flashes of light of 0.015 second duration. The subject regarded a red fixation cross and reported on the appearance of a flash which appeared at an angle of 15 degrees in the periphery of the eye. The intensity of the flash was controlled by means of a neutral-tint wedge and balancing wedge.

Seven cards with illuminated areas were used during the experiments. Each card contained two semi-circular apertures of 0.5-degree radius. In successive arrangements the distance between the semi-circles varied from no separation, i.e., a complete circle, to a separation (in terms of visual angle) of 150 minutes. The semi-circles were so arranged that one of the stimulus patches remained in the same constant position, the other being moved toward the periphery. These patches are designated as the "fixed" and "variable" patches, respectively. The patches could be illuminated simultaneously or singly.

Dark-adaptation was maintained for from 40 to 45 minutes before the first threshold determination. The procedure was the same for each measurement: First the threshold was determined for both semi-circles together, then for each alone; and finally for both together again.



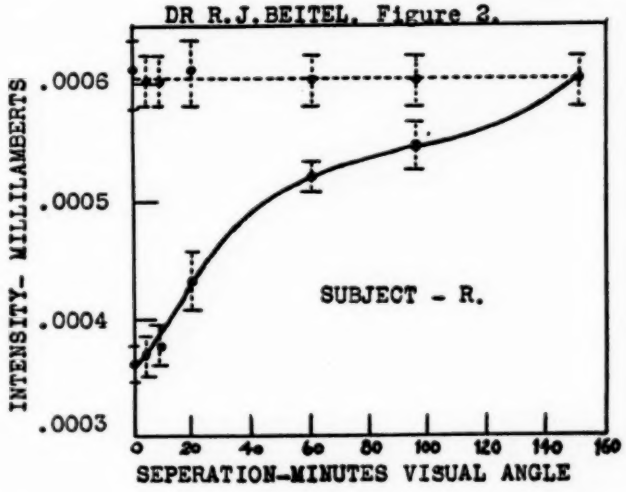
Curve of averaged Threshold Intensities obtained for both patches when exposed simultaneously at the separations indicated. The top dotted line is drawn through the points corresponding to the averaged values of the single patch having the lower threshold valve at each particular setting. The "fixed" patch is at 15 degrees in the periphery.

Results of the Peripheral Determinations

The average results for four subjects are given in Figure 1.

The figure shows that as the distance between the two patches decreases the threshold intensity decreases. At a separation of 150 minutes the threshold for both patches is the same as the threshold for either of the single patches—within the limits of a slight degree of variation. Thus when we plot the threshold values of the single patches on this graph we find that curve to be very nearly a straight line across the figure at an intensity value corresponding to the value for the widest separation. The difference, then, between these values and the values as plotted (solid line) is some indication of the summation due to the presence of the second semi-circle.

Inspction of this graph makes it clear that the range of variation in intensity is small—a range of variation of 1 to 2. Because of this small range it becomes necessary to consider the variability of the data. We must ask: How can we be fairly certain that the differences between the thresholds for the different separations are significant? An answer is given in Figure 2.



Curve for one subject showing the range of the Interval of Uncertainty for each determination. The "fixed" patch is at 15 degrees in the periphery.

In discussing these results it is necessary to give some description of the method used for the determinations. Obviously, in measurements of this kind we are not interested in determining a representative value for the subject's discriminating behavior. Rather, we are interestd in getting a complete series of determinations in a short time—during

which time the subject is presumably in a stable physiological state, and during which time his threshold values are highly reproducible.

In order to fulfill this requirement the method of limits was used. The subject's response was tested five times with an ascending series and five times with a descending series over a range of wedge readings which were shown by preliminary experiments to embrace the range of uncertainty. The intensity below which the response was always "No" was recorded, as was the intensity above which the response was always "Yes." Thus in Figure 2 the range of the resulting interval of uncertainty is plotted for a subject whose total range of intensity variation was smaller than that of any of the other four subjects.

Although the curve for this subject is the most atypical, it nevertheless possesses the characteristics displayed by the curves for the other subjects: the initial sharp rise, the intermediate interval of comparatively little change, and the final upswing to the point for the widest separation. With the exception of the determinations made for the separation distance of 150 minutes, the absence of any overlapping between the ranges for the single patches and those for both patches together is quite evident. Thus it seems that there can be little doubt as to the reality of the summation effect.

Apparatus and Procedure: Foveal Determinations

In the attempt to determine similarly the nature of the effects exhibited in the fovea, difficulties were encountered in securing adequate fixation which necessitated modifications of both apparatus and procedure. These difficulties were peculiar to the type of method tried and took such forms as extreme fatigue, accommodation and convergence variations, and "Autokinetic phenomena." It was decided finally to employ a method whereby the determinations of difference thresholds, rather than absolute thresholds, could be used.

The apparatus was so arranged as to permit a dim, diffuse illumination of the cards bearing the stimulus patches. In the center of each card, and slightly below (5 minutes, in terms of visual angle) the level of the stimulus patches, was placed a small wedge of light gray paper which served as a fixation object. The intensity of illumination on the gray fixation-spot required to make it just discernible at the fixation distance was determined by preliminary test following a 5-minute period of dark-adaptation and was maintained constant throughout the experimental period.

Five cards bearing stimulus patches were used in the experiment. Each card contained two square apertures, the sides of each square subtending a visual angle of 5 minutes. In successive arrangements the distance between the squares varied from no separation, i.e., a complete rectangle the longer side of which subtended a visual angle of 10 minutes, to a separation (in terms of visual angle) of 30 minutes. The squares were so arranged that the fixation-object always occupied a position

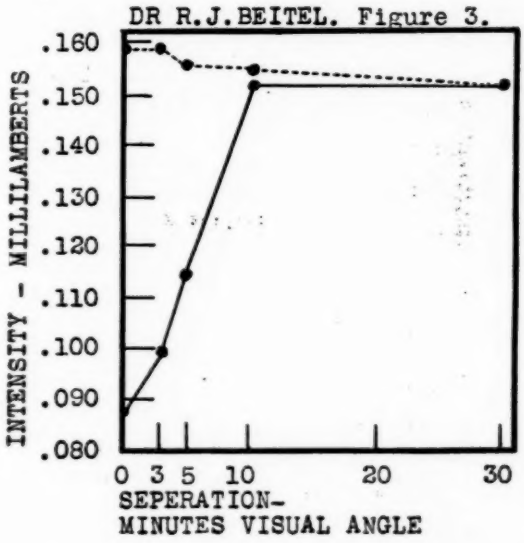
midway and slightly below the level of the patches. The patches could be illuminated simultaneously or singly.

Each subject was first light-adapted for 2 minutes, then dark-adapted for 5 minutes, prior to the determination of each threshold.

The method of determining the threshold values was essentially the same as that used for the peripheral determinations. Binocular fixation was used for all the determinations.

Results of the Foveal Determinations

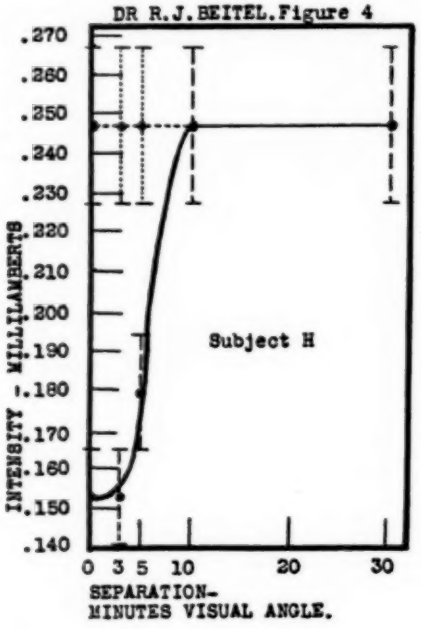
The averaged results for four subjects are given in Figure 3. This figure shows that, within the range of no separation to a separation of 10 minutes, the threshold intensity decreases as the distance between the two patches decreases. Within the range of 10 minutes to 30 minutes of separation no change in threshold intensity is found. The dotted curve



Curve of averaged Threshold Intensities obtained for both patches when exposed simultaneously at the separations indicated. The dotted line is drawn through the points corresponding to the averaged values of the single patch having the lower threshold value at each particular setting. The determinations are made for the fovea.

is drawn through the points corresponding to the values of the single patch having the lower threshold value at each particular setting. The difference between these latter values and the values as plotted for the two patches together affords some measure of the summation due to the presence of the second patch.

An indication of the nature of the variability exhibited in the foveal data is afforded by Figure 4. In this figure the range of the resulting interval of uncertainty is shown for each separation used with one subject whose responses were quite consistent. (The results for the other three subjects are similar, differing only in that their values for the single patches are slightly more variable.) The dotted line, again, is representative of the threshold values corresponding to the single patch having the lower threshold value at each particular setting. Thus it is seen that the differences between the thresholds for the various separations are quite significant and that there can be little doubt as to the reality of the summation effect.



Curve for one subject showing the range of the Interval of Uncertainty for each determination. These determinations are made for the fovea.

Discussion

The results of these experiments show that there is evidence for interaction between spatially separated, subliminally stimulated areas in both the periphery and fovea of the retina. The amount of this interaction is a function of the distance separating the stimulated areas, the effect increasing with increased proximity of these areas. The experimental facts show that this process occurs over a limited range in both the fovea and the periphery. In the periphery, when the patches are separated

by a visual angle of 2½ degrees, and in the fovea, when they are separated by a visual angle of 10 minutes, no effect can be noted. Under these circumstances the threshold intensity for both patches is the same as that of the single patch having the lower value. These results, insofar as they demonstrate interaction of a summative nature, are in line with those obtained by Adrian and Matthews[3, 4], Granit[13, 14], and Granit and Harper[16] in their studies on spatial summation where supraliminal stimuli were employed (see "The Problem").

The decrease in threshold intensity with a decrease in separation of stimuli is most easily interpreted as being due to an increased lateral summation which arises with an increase proximity of converging excitatory paths. Arguments for such an interpretation have been advanced at great length by the authors previously cited, and there is little reason for further discussion of this point.

In the peripheral retina convergence is exhibited in three forms: (1) convergence of many receptors upon one bipolar cell; (2) convergence of two or more bipolars upon one ganglion cell; and (3) the convergence of lateral internuncial neurones at a common focus. It is clear that the convergence of receptors upon a single bipolar cell cannot explain a summation which occurs over a spatial interval of 150 minutes of visual angle. Nor can the convergence of bipolars upon ganglia explain the complete effect—although it is probable that the initial sharp rise in our curves may be correlated with these influences. The threshold, then, must be determined to some extent by the amount of interaction taking place over the lateral internuncial neurones. In this connection it is interesting to correlate our result, which shows summation over a visual angle of 2½ degrees, with the anatomical finding of Ramon y Cajal[20] that the limiting length of the lateral interconnections of the eyes of higher vertebrates is .8 mm. (corresponding to approximately 3 degrees of visual angle).

Similarly, if we consider the anatomical evidence, it may be possible for us to account for the initial sharp rise in the curves in Figure 1 and 2. Figures given by Chiewitz[6] and Koelliker[18] on the relation of outer nuclei to ganglion cells in the periphery permit us to assume that spatial summation up to a separation of 20 minutes is largely mediated by the convergence of outer nuclei upon ganglia. Summation occurring over greater spatial intervals (up to 2½ degrees) will have to be explained, then, in terms of convergence afforded by lateral internuncial neurones.

In the fovea, as is well known, anatomical convergence is quite strictly limited. For the most part evidence points toward a 1-to-1 relation between receptors and ganglion cells, but bipolars, amacrines, and some horizontal cells have been demonstrated (Ramon y Cajal[20]; Koelliker[18]). The number of ganglion cells increases greatly from the center of the foveal pit to the margin of the fovea, as do the the bipolars.

Our results for the fovea, which exhibit summation within the limited range of 10 minutes of visual angle, correlate with this evidence. In contrast with the periphery, where converging pathways provide a basis for summation over approximately 2½ degrees of visual angle, the fovea exhibits little in the way of converging paths. However, the evidence indicates that summation does occur. In view of our knowledge of foveal anatomy the mechanism for this summation in the fovea may well be accounted for in terms of a spatially restricted, "direct" type of convergence.

This appearance of interaction at the threshold in both the fovea and periphery is a finding of considerable significance in that it carries an important implication for interpretations which deal with the nature of the threshold itself. From the interpretations given above it follows that, in order to summate with another subliminal stimulus, the excitation due to one subliminal stimulus must reach a region of the nervous structure upon which the pathways from the two stimulated areas converge. Further, the results show that the excitation due to a subliminal stimulus may reach this region without causing a light-discriminatory response on the part of the subject (i.e., the subject does not "see" the light). Such a response does not occur unless the excitation due to the stimulation of one region is reinforced by the excitation due to the stimulation of another region. This type of process is, of course, a nervous process and, by its nature, may occur in any part of the retinocerebral system. However, the evidence at present is of such a nature as to indicate a retinal locus for the process. Thus, the investigations of Adrian and Matthews[3, 4] and Granit[14] have shown that functions of a similar nature are demonstrable in the excised eye and in decerebrate preparations. Obviously, in the case of the excised eye the only nervous structures which could account for the effects are the retinal layers. Since these observations on infrahuman "preparations" are directly comparable with the results reported in the present experiment, it would seem that, in the present instance, it would be well to consider the effects as due to the activity of the retinal synapses. In view of these considerations, the final (threshold) response is judged to be initiated and controlled by the processes in the retinal layers and ganglia.

Summary

Threshold intensities have been determined for various separations of two stimulus areas in both the fovea and periphery of the human retina. The results are interpreted as demonstrating interaction of a summative type between subliminally stimulated areas. The amount of this interaction is a function of the distance separating the areas. Arguments are presented for the conclusion that the locus of the visual threshold effect is in the synaptic layers of the retina.

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RESTORATION OF ABILITY TO READ WITH EITHER EYE AFTER TRAINING ONE EYE IN A CASE OF SUB-NORMAL VISION*

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The case reported is that of Mr. J. D., age 78, who came to us complaining of poor vision at all distances. He stated that, under the most favorable conditions, he could read only the titles of newspapers. He was able to go about alone in or out of doors, although on bright days he used glazed blue-lens spectacles. He reported vision was better at twilight. The patient first observed his vision to be failing a little over three years prior to this examination, the diminution of vision being progressive for about two years. He had not been able to read newsprint for three years and for two years had not been able to read anything more than newspaper headlines. He had even lost the ability to do this one year prior to consulting us. There was no asthenopia. The patient had first consulted an oculist who administered local medical treatment for six months apparently without any effect. Other practitioners of various schools subsequently consulted did not prescribe any treatment. On his own initiative, the patient tried a magnifying glass, which proved to be of no help. By using the reading portion of a bifocal correction prescribed ten years ago, he was able to tell the time by judging the position of the hands on his pocket watch. On the street, he saw and felt better without his correcton, which was O.U. +1.50 D.S. add +2.75 D.S. He was chiefly interested in being able to read.

Examination gave the following findings:

N.V.A. O.D. 6/200 O.S. 6/200 O.U. 6/200 (3%).

No manifest deviation. Near point of convergence, 15 cm. Pupils small, react to light and convergence.

Ophthalmoscopy: Crystalline lens dull in both eyes; some central and paracentral choroidal involvement, in both eyes, the maculae being within the affected areas; sclerotic change in the fundus. Hand slit-lamp: sclerotic changes in crystallines, but less than that usually found in individuals of the age of the patient. Fields: form field practically normal.

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*An abridgment of the material presented before the American Academy of Optometry at Cleveland, Ohio, December 16, 1934.

Keratometry: O.D. 0.25 with the rule, O.S. 0.25 against the rule.

Static skiametry: O.D. +1.25⌒—0.50 x 15 O.S. +1.25⌒ —0.25 x 75.

Subjective refraction: O.D. negative O.S. 1.00. Very slight improvement of distance vision with T.S. 2.2x. No favorable reaction to ordinary lenses for near vision. With T.S. 2.2x, add +10.00: O.D. no reaction, O.S. reads 1F; add +13.00: O.D. no reaction, O.S. reads 2F. With M.S. 8x, reading vision slightly improved.

Despite these rather unsatisfactory results, the patient seemed encouraged, even if we were not, and we decided to see him again. On the second visit, the patient rejected, subjectively, all ophthalmic lenses for distance. Other findings confirmed those of the first visit except that with the microscopic spectacles the patient read: O.D. to 2F with considerable difficulty, O.S. to 4F with slight difficulty. The patient was able to read the time on his watch either with M.S. 8x or +10.00 D.S. (mag. 2.5x), but preferred the latter.

Visual training was thereupon instituted and continued over a period of six months, beginning with primers and proceeding to 2nd and 3rd grade books, etc., to 6th grade books, magazines, novels and newspapers. At first the training was entirely in the office, employing the M.S. 8x and M.S. 12x. After one month the following prescription was given:

Rx O.D. Plano (no add). O.S. Plano add +6.00.

Sig. constant wear. Ft. opifex cement bifocal. The segment was prescribed for telling time; the plano carried the segment and was also of the nature of a placebo.

After two months treatment, the patient was supplied with spectacles with

Rx O.D. Plano lens. O.S. M.S. 8x

and reading practice at home began. Three months later a series of careful comparative tests were made with M.S. 8x and T.S. 2.2x with CRA 2+10 and the final reading prescription ordered:

Rx O.D. M.S. 8x. O.S. M.S. 8x

for monocular reading with either eye; and, in fitover form, for outdoor use on bright days:

Rx O.U. Plano Cruxite B.

The patient's native tongue is German, although he learned English many years ago. For the third visit we had secured some German printed matter having suitable word-content and type size. The patient reported he could not read the German, then added, "I can see the letters clearly —about like the English—but I can't read the German words." This experience was twice repeated. We learned that for the two years prior to losing his reading ability, the patient had read practically no German, although he occasionally spoke the language. We continued the training in English.

The first time the word "bread" appeared in the context, the patient spelled it aloud—"b-r-e-a-d"—then pronounced the word "bread." Fifteen minutes later the word occurred again. The patient studied it silently for a moment and then said "brot" (German for "bread"). It would seem that the memory picture of the word "bread" recalled the visual (and olfactory?) memory picture of the object with which was associated the German name "brot."

About ten weeks after treatment was begun and two weeks after home training was begun with M.S. 8x, the patient attempted to read English newsprint and large type German material; began to decipher German newsprint after another two weeks and after a month's practice, felt he could read German "quite well." A little more than four months after training had been instituted, the patient reported being able to read German or English newsprint equally well (Figure 1). He remarked that although the German type was "fancier," and for that reason more difficult to read, it was also larger, an offsetting factor.

The patient had first been seen March 31, 1934. On August 10th, observations were made on the patient's vision, as follows:

N.V.A. O.D. 6/132 O.S. 6/132 O.U. 6/132 (about 4.5%).

Subjective: No. 1—

O.D. Plano T.S. 2.2x, add +10.00. Reads to 5F with difficulty.
O.S. Plano T.S. 2.2x, add +10.00. Reads to 5F with ease.

Subjective: No. 2—

O.D. Plano T.S. 2.2x, add +12.00. Reads to No. 3 English type.
No. 2 German type.
O.S. Plano T.S. 2.2x, add +12.00. Reads to No. 4 English type.
No. 5 German type.

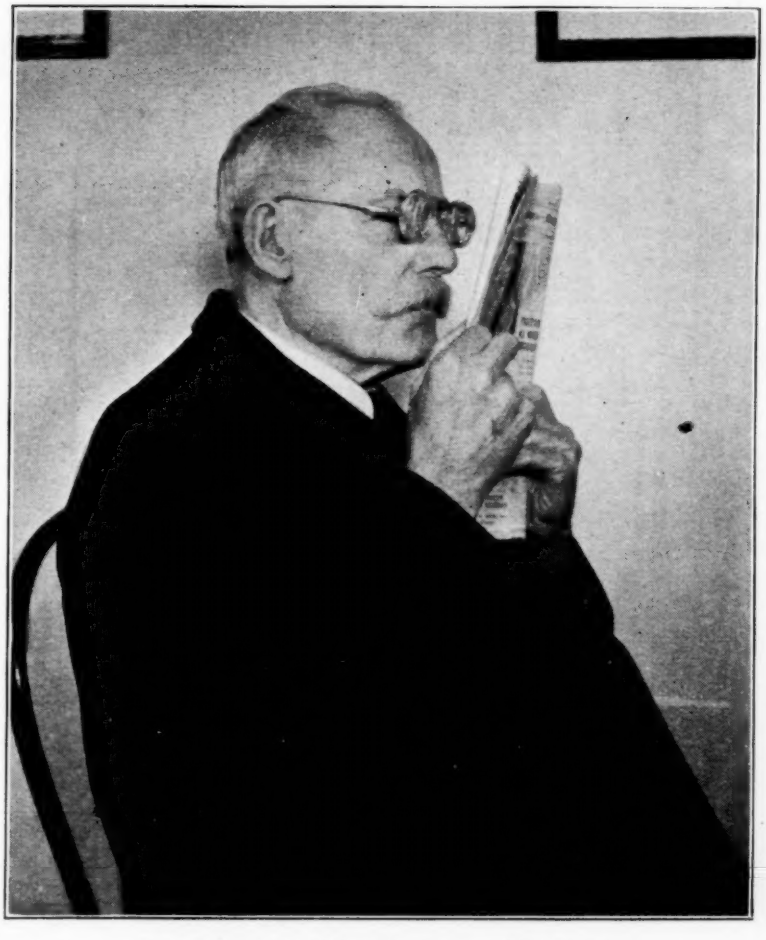
(Test types not previously seen. German type used is larger than the correspondingly numbered English type. Standard test charts.)

Subjective: No. 3—

O.D. M.S. 8x. Reads No. 4 English type with difficulty.
O.S. M.S. 8x. Reads No. 5 English type with difficulty.

It should be noted that this was the first occasion in four months that the right eye was used for near vision. Those words with which the patient had become thoroughly familiar, using the left eye, were more easily read with the right eye than other words, to about the same degree (of greater ease) as with the left eye.

When last seen (mid-October), when the prescription was given for the right eye, further improvement was observed in both eyes, but especially the right, the vision of which was almost as good as that of the left. The patient remarked that his distance vision had improved greatly during the period of treatment; he was able to tell the time by the mantel clock, previously impossible, at a distance of several feet and added that he could read the time on his watch "with the upper part of the street glasses" (plano). The segment addition was therefore removed.



Dr. Charles E. Jaeckle. Figure 1. Patient Reading.

The patient's expressions of gratitude were such as to be embarrassing, but should serve to impress us with the significance and importance of bringing to these cases patience, understanding and a sympathetic desire to relieve affliction. "Now, doctor," he said, "I can anyhow read a little when I want—I don't have to depend on somebody else."

Summary

In the case under consideration, the patient had not been able to read for two years and had not read his native language (German) for two years prior to the loss of ability to read.

Although the distance visual acuity was the same for both eyes, the ability to read with the aid of optical devices was much better for the left eye than for the right.

With the aid of suitable optical devices, used before the left eye, visual training was carried on for a period of six months.

The patient was at first able to read only English, the ability to read German returning only after ten weeks.

The patient was able to read with the right eye fairly well, as compared with the left, after four months training of the left eye only; after six months training of the left eye only, the difference in reading ability of the two eyes was further lessened.

Conclusions

The fact that the naked visual acuity improved is evidence that some change must take place in the patient's ability to see, which is not dependent upon the purely optical assistance given. Obviously, this change does not consist of restoration to its original state of retinal tissue damaged by pathology. The improvement effected in reading vision was as pronounced in the "untrained eye" as in the "trained eye." We have been dealing, therefore, with processes beyond the retina, beyond the optic nerve and the tract, in the higher brain centers. Two types of learning are demonstrated in this case. First, there is the development of perception; the patient learned to recognize printed words by his visual impressions and learned finally to recognize smaller images. Second, there is the development of motor reactions and responses in association with perception: the patient learned to speak correctly through the words he saw—to say "bread" and not "brot," for example.

The case reported clearly confirms the fundamental principle which we have come to recognize, that the treatment of sub-normal vision is an educational process. "Sight" is indeed "memory."

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DISCUSSION

DR. BEITEL: There are a number of points, both of practical and theoretical significance, that Dr. Jaeckle has presented in his paper. Inasmuch as I did not have an opportunity to read the paper beforehand, I shall ask the privilege of asking a few questions before I say more. Did the patient in losing his ability to read have apparently a similar loss in both eyes at the same time?

DR. JAECKLE: He was a little vague, but as far as he knew the change had proceeded simultaneously with both eyes.

DR. BEITEL: With the first correction, am I correct in stating that his vision was somewhat improved? Was it then improved enough to enable him to read large distant signs with either eye?

DR. JAECKLE: No. At no time was his uncorrected distance vison, with other than telescopic spectacles, better than 6/132.

DR. BEITEL: In the training of the left eye was the right eye perfectly occluded?

DR. JAECKLE: No, but I think that it might just as well have been, because he could not recognize anything held at a near point with the right eye without lenses. Even now, with microscopic spectacles for both eyes, he simply reads with one eye but occasionally changes over and uses the other.

DR. BEITEL: Were the same stimuli used in the training of both eyes constantly, and if the material was changed at all how often was that change made on the eye that was being trained?

DR. JAECKLE: We started with the sub-normal vision reading card, and after the third visit began to read the printed matter. He would read and re-read the primer until he had completed a short story. When he finished the first-grade book, he then used the second, and in that way went through our training library.

DR. BEITEL: So far as I know this is the first clinical demonstration of transfer training or cross-education in the visual function. There has been some work with normal subjects in which this type of visual transfer has occurred and in which the transfer is practically equal to the full development of the trained eye. I refer to the work of the late Dr. Shepard of California, which I think was published in 1933.

The topic of cross-education, is, of course, of great practical significance in this rehabilitation work in vision and suggests many interesting problems along this line. As far as the theoretical implications are concerned. I think that Franz would state that the theoretical interpretation of this type of behavior is that the transfer is not a transfer in the ordinary sense of the word, such as when we train the right hand in a certain task, and then try the effect on the left hand and find the left is better than before the right hand was trained although not as good as the right hand.

In a transfer effect of this sort, the transfer effect of the untrained eye is, apparently, equal to that of the full development of the trained eye. I think Franz' conclusion would be that the cerebral areas involved present a situation which would be very similar to a direct carry-over effect, rather than a transfer effect.

DR. FEINBLOOM: As was just pointed out, this case presents an excellent example of the problem of transfer of training in locus co-ordination. The chief problems involved in the case of learning to read with sub-normal vision devices of the type of these microscopic spectacles are two in number, one of which is a matter of motor coordination between the arms or hands, the eye movements and head movements.

When we consider such motor coordination we can appreciate that any training carried on with one eye would necessarily involve a training of the other eye, even though the stimulus was removed. The coordination developed, for example, when the left eye in this case was trained, involved certain types of eye movements, and ocular focusing and at the same time the same functional changes were being carried out by the left eye.

As far as the second problem, that of cross-education, is concerned, the training undoubtedly is cerebral in the sense that the patient was relearning material and the cues that he at one time knew, so that possibly your suggestion of training the good eye wouldn't apply here because essentially it is questionable whether there was any improvement in actual visual acuity in either of the eyes after the training processes. I might mention that this result is not uncommon in sub-normal vision work. We almost always find where both eyes are of equal visual acuity that training in one, as far as reading ability is concerned will produce equal reading ability in the other eye.

One other point occurred to me, when Dr. Jaeckle said that at the end of the training the subject could recognize the time on a clock some distance away.

These patients often develop a system of telling time that is quite independent, for the most part, of any visual acuity. Time and again the subject will report improvement in ability to tell time, but, if you test him by setting the clock at odd hours he really cannot tell the time indicated by the clock. They learn to associate the passage of time with ordinary events of the day, and they can tell you without ever looking at the clock what time it is.

I am cetrainly pleased that Dr. Jaeckle took the time to present this report so fully as it presents clearly the whole point of transfer.

CHAIRMAN MELVIN: From another viewpoint could it not be that the individual, once he has mastered the interpretation of an imperfect retinal image with one eye has developed a faculty of interpretation which can be utilized by the other eye?

DR. JAECKLE: Yes. Such is a practical viewpoint. The point was made that in this case the patient re-learned something he knew before. I have under observation several sub-normal vision cases which have never learned to read well but which I am treating in the same way. They are not re-learning, and we shall see whether or not they also can read with the untrained eye as with the trained eye.

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BRITISH OPTICAL ASSOCIATION ACHIEVEMENTS

While the American Optometrists may pride themselves upon having won legal recognition in the various States in the Union, something our British colleagues so far have been unable to accomplish—yet from the standpoint of achievement the British Optometrists are by far ahead of the American Optometrists. They have, to their credit, many of the material and spiritual accomplishments which we should aim to achieve. We should set these as our goal. We shall mention here only one, and that is the Library of the British Optical Association. It is an institution of which any profession may be proud to possess.

From the history of the "Library" we learn that it had a very modest beginning. The first catalogue published by the Council of the Association consisted of seven Optical books. This number was considerably increased through private collections, donations and purchases which were made possible through substantial grants from the Association Funds. The Carnegie Foundation Grant of 1000 pounds enabled the council still further to increase the number of books until today it is

considered to be one of the most comprehensive Optical Libraries in the world.

In 1932 a comprehensive Library Catalogue was published. It contained about four hundred pages. During the last three years so many valuable additions have been made, mostly in modern works that the Association found it necessary to publish a supplementary catalogue of about 140 pages. To be more specific, over 1000 new books and reprints have been added during the short period of time since 1932.

The Library prides itself of possessing many old and valuable books, the most valued is the copy of Peckham's "Perspectiva." This is the oldest book in the library and dates back to 1504. It is remarkable for its wood cut illustrations.

The Library is housed at 65 Brook Street and offers every facility for parctitioners and students interested in research work.

The British Optical Association also maintains a very elaborate museum with extensive and complete displays. At this writing we are informed a special catalogue will soon be published about the museum, and other institutions established and maintained by the leaders of the British Optical Association of which we shall have occasion to comment in this publication at some future date.

These are some of the things that the optometrists of England have been doing to enrich themselves and their profession. From a cultural standpoint these are fundamental and go far towards laying a firm foundation to future professional growth. And in so doing they have drawn towards themselves educators and persons of note and stability in their country which adds much to the splendid position they enjoy throughout the English speaking lands.

Their associations too, interest themselves in major educational movements of a real and lasting character. The various Refractive Hospitals in their major centers are witness to the interest shown by the rank and file in the profession in England in matters of sound educational value, and the funds which have been gathered by these associations have been put to good use in these schools of learning. As American optometrists we have much to learn from our English cousins and our local associations could well copy much of value that they are now doing.

—J. I. Kurtz.

SPECIAL REPORT

SCIENTIFIC PROCEDURE AND ITS MISAPPLICATION*

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In applied sciences such as mathematics, physics and chemistry, basic hypotheses are assumed from observational data and a logical structure is built upon these assumptions, subject to constant supervision and revision from the laboratory. The conclusions thus reached can be challenged only by reverting to the basic assumptions themselves and either proving them to be wrong, or assuming an equally logical but different axiom or "self-evident" truth for a starting point. The edifies so constructed will vary, stand, or fall according to the ultimate correctness of the basic assumptions made at the start.

If as in philosophy, different thinkers may assume widely differing basic hypotheses, and we thus ultimately obtain an almost infinite variety of "systems," all logical *if* the original assumption be accurate. Inasmuch as these basic assumptions can never be proved with any degree of finality, the furor of debate, argument and counter-argument rages through the centuries, as it will so continue to rage.

The physicist, astronomer, and no less the pure mathematician proceed first from observation (sometimes faulty) to the expression of hypotheses, "these hypotheses *after experimental substantiation* becoming laws upon which practical men may rely in the application of these discoveries." (This writer's italics.) Notice carefully the clause "after experimental substantiation." Without this substantiation, any thought-edifice or system may be casually destroyed by the first whiff of oratorical verbiage.

In the study of sociology, economics and in psychology, we may witness their inception as "sciences" upon a basis of more or less accurate observations, but lacking in any experimental proof whatsoever; hence they are not exact sciences at any given time except where and in such instances as they have been taken to the laboratory, torn apart, investigated and proven beyond reasonable doubt, at which time an hypothesis becomes a law. Witness again: this "law" cannot be questioned except by starting from another observation and reformulating the original assumption. It is interesting to note that psychology began its advance as, or towards, an exact science only when its problems were thrown into the proving grounds of the laboratory.

In economics and its rather more philosophical relation, sociology, the laboratories are so vast and the subjects so unwilling that it has

*Submitted for publication June 18, 1936.

taken an international catastrophe to start the experimental ball rolling, so that we may now witness social experiments on an unprecedented scale; the point is, however, that these latter subjects are notorious for their inexactness.

If this preamble has been unduly long and its relation to optometry obscure, we now arrive at the point of the whole matter. Very briefly, we might say that the subject is this: Is optometry being taught and practiced as a true science; are the leaders taking their problems to the laboratory, or are they making observations and formulating hypotheses and then offering these hypotheses as *law* without the intervening experimentation and substantiation? In short, are we progressing as men of science, or is our profession functioning as a debating society? The answer and solution is the answer to the future of the profession. Let us attempt the answer.

One example will strongly suggest the answer and its solution as above outlined. It is that of the controversy that has raged over the use of cyclopegics as a refractive aid. (This is a blacker eye for medicine than for optometry; they, at least, have had the facilities for many years for settling the matter.) I shudder to think of the tons of verbiage that has been published over this easily established proof, over the cubic yards of gas that have been released in the manner of the typical high school debating society in trying to settle the problem on a basis of who could talk the longest and the loudest. Did a single optometrist or optometric institution roll up its sleeves and undertake to *search for the truth regardless of the issue* in all those years? Search the literature as far back as your files of our journals will allow and you have the answer; last April's American Journal of Optometry contains the first preliminary report ever made, to our knowledge, by Tait and Sinn, made under laboratory conditions, and directed by a recognized man of science. (How many of the latter, by the way, do we have in all our optometric colleges put together?) Look this article up and reread it; let the full significance and import of this method of investigation make its full impression on your mind. Then, and only then, consider the material that is being offered to you today in article after article on "onics," "isms," "points," "routines," "analyses" and "foundations."

Is it necessary to point out that in order for any man to judge all this mass of undigested material that he first must thoroughly discipline his mind with all the underlying sciences that go to make up the basis of education for any professional man? Due only to our lack of this basic training, by and at large, is it possible for all of the courses and trick schemes now being foisted upon us *to be profitable* to their originators? We are now ready for the answer to the previous question as to our present methods of solution to our problems.

We now find an amazing thing; a whole series of hypotheses are being taught as unquestioned laws, some of these concepts *not even hav-*

ing a foundation in observation, to say nothing of the necessary substantiation and laboratory proof. Allow us to point out that such a procedure is not even creditable to a debating society, while as a scientific method it is the ultimate *reductio ad adsurdium.* To disprove the *dicta* now being presented is the merest child's play, and while an occasional refutation is offered by a man trained in the laboratory, most thinking men hesitate to enter an arena befogged with the smudge of oratory and the flying missles of half-truths.

As long as this phase of the science of optometry prevails, no very great progress can be expected. Except for the opposition of the medical leaders to undergraduate specialist training and its attitude of *laissez faire* in this regard, we would no longer exist as a profession. Make no mistake about this; the time has been ripe for a good many years for any group to take over the field of eye-work; strangely enough, the opportunity has gone unnoticed, and is still neglected. The first group that trains itself properly will unquestionably gain the entire field for itself, and will certainly retain it as long as its educators proceed along the proper lines in the training of its undergraduates.

The analogy between dentistry and optometry has been drawn so often that I apologize for making it again, but do we not, after all, desire the same latitude in our practice as they have in theirs, their laws allowing them to practice all that they have been taught? It seems to me that we do, despite the protestations of our conservative element to the contrary. I will, however, agree with the conservatives that we are not prepared *at this time;* further legislation must follow rather than precede proper training. We cannot go to the various legislators and say, "See here, we've been studying a lot of this and that for several years now, and we don't think anyone else has, so we want you to turn over the entire field of eye practice to us because the medics don't know theoretic optics anyway." Hardly. To the contrary, let us order our collective intellectual houses in such manner that we may go to these legislators and say, simply, "WE have covered the field thoroughly, here is the proof, allow us to practice what we alone can demonstrate our ability to do properly, what we have been taught." Doesn't that cover our professional ambitions? Or is it that we have no ambitions, professional or otherwise?

Kurtz says that optometry has been under a condition of hypnosis during the past few years. We agree, but would like to amplify the statement. We've never been any other way, with pathetically rare individual exceptions; the past few years have served only to prove this by the material that we have accepted, with hardly a question, as inspired or divine law. Mass hypnotism is not new, neither is the cure for its resultant evils. Merely *ask why, demand proof, and refuse to be put aside with oratory or oratorical chicanery.*

There is a gleam of hope, however, in the fact that mass hypnotism can be practiced on the subject of learning. If the profession wants educa-

tion, why not give it to them in the proper, basic form, you educators? The search for truth is a difficult one, is met most often with jeers and indifference, but the results justify the effort and humilitation met with. We have some information that a course is now being worked out for the graduate optometrist in the basic sciences, to be offered through an extension program that will require several years for completion, to be supplemented by yearly laboratory training of about a week. We suggest that this course be offered in a manner that will allow it to be national in scope and character. If and when such a course is made available, it should be adapted at the earliest possible moment by the state societies and put into practice by the "group" method. This gives the individual the feeling that he is not alone with his difficulties, and gives him the moral courage to begin at the beginning and master the work as it is presented.

The idea back of an extension course of this kind, offered by an institution with an adequate faculty, is that we cannot go forward until we have gone backward to build the foundation that should have been present all along. It should, however, be borne in mind that this course and others which we hope will follow it are not an end in themselves; they are more of a means to the end of extending optometry to the natural limits that will encompass the entire field of eye work, with the accompanying legislation that will keep incompetants out of the profession entirely. *Undergraduate training will necessarily keep ahead and lead the procession* so that the graduates will be well abreast of all developments from their first moment out of school. Only one school in the country but that needs this last warning.

Regarding the present work that is, after all, all that we have at present, a leader in this state recently said to me, "Well, doctor, tainted meat is certainly better than no meat at all." There is a great deal more to that than appears at first thought, but our appetite for tainted meat is in no way improved by this consolation. The solution to the analogy lies, of course, in ignoring the bad meat and searching a bit further for some that is good; *it's there*—it's just a bit more difficult to uncover, and when discovered may not look as spectacular as the other kind. We certainly wouldn't advocate removing tainted meat or education from anyone starving for either, unless something better were at hand; in this instance we're advocating that the better material at hand be made more readily available and presented in a palatable form.

State societies and their leaders should take heed that unless they avoid converting their groups into Greek choruses with the sole purpose of promulgating the unproven theories and theses of men without scientific background, that they will presently find that they have lost prestige in the eyes of their colleagues. Possibly this would be no unalloyed evil, in every instance.

Graduate students, and in many cases undergraduate students, are today too often being presented with the answer to their technical prob-

lems with a finality that does not suggest that the answer to many of these problems has yet to be discovered; this is a gross pedagogical error, tending as it does to "fix" many misconceptions, as they are later discovered to be, in the minds of those thus inculcated, and what's worse, to give these students the idea that what they need further is less experimentation and more deduction. The final result of such a procedure is the condition now being discussed: a group of men ready to accept, and pay for, very nearly anything that is offered in the field of what should be an advanced and rigorous science, the only requirement being that it look and sound pretty.

Let us then exercise the following cautions before accepting *any* man's teachings: Ask for the source of the assumptions upon which the course or idea is based; determine whether the hypothesis is drawn from observation or has been developed through deduction, and if the latter, examine the premises for error; examine all deductive processes with suspicion of error in logic, of faulty premise, and of illogical development; require reasonable substantiation before accepting an idea even as a tenable theory, and require exhaustive substantiation before accepting this theory as law. Finally, and of greatest importance, don't accept this law as being final; it may be modified or disproved next week or next year. leaving you in an intellectual backwash difficult to struggle away from. Remember that truth is a goddess with many faces, and that all of them are not white.

DR. JAMES O. BAXTER, JR.,
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BOOK NOTICES

VISUAL FIELDS. T. A. Brombach. Published by the Distinguished Service Foundation of Optometry, Fall River, Massachusetts. Marketed by the American Optical Company, Southbridge, Mass., and their branches. 228 pages, illustrated with 48 colored plates. Cloth. $10. 1936.

For many years Brombach has worked clinically with thousands of patients in an effort to establish some degree of correlation between toxins and visual field changes which these toxins produce. This was naturally a difficult matter and one which could only come about through the patient effort of an investigator who was willing to chart field after field time after time and thus amass data which could then be studied

and referred to as new material came to hand. The author of this book spent years working on this research before making any statements whatsoever about the matter and this text is his first major presentation to the optometric profession relative to this as yet new diagnostic work.

Of course, perimetric field charting has been done for years, yet Brombach was the first to refine the techniques to a point wherein color field charting could be clinically used as a diagnostic finding. In his book he devotes the first six chapters to a review of various methods of field charting and the remainder of the book to the study and clinical application of the work itself. This text is a clinical reference book. The colored plates are beautifully done and are so included as to be at hand just where they are referred to in the text. Each phase of this study is thoroughly covered and much of value has been added to the literature of the profession by Brombach in this new book on his Visual Fields. The work is an inspiration to every optometrist and will stimulate many to enter this new phase of optometric procedure and thus render a more finished service to their patients. The edition is limited and optometrists wishing to secure a copy should order it at once. C. C. K.

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LECTURE DELIVERED BEFORE THE IOWA OPTOMETRIC ASSOCIATION. Harry L. Foug, Opt.D. Published by Dr. F. L. Hoefle, Secretary, Iowa Optometric Association, Orange City, Iowa. 16 pages. Paper covers. 1936.

This is a report of a lecture delivered before the Iowa Optometric Association by Dr. Harry L. Foug of Los Angeles, Calif. The published monograph deals first with a review of Snell and Sterling's work in the field of visual efficiency, then with visual fatigue and the possible effect of visual fatigue on the size and shape of the visual fields themselves. Foug brings in the work of Brombach and goes into some detail in referring to studies which have been made by optometrists of the size of the various color fields and the parts these play in the diagnostic work of our profession. —C. C. K.

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